FREQUENCY DISTRIBUTION AND CORRELATION AMONG MINERAL ELEMENTS IN *LYCIUM ANDERSONII* FROM THE NORTHERN MOJAVE DESERT

A. Wallace[1], E. M. Romney[1], G. V. Alexander[1], and J. E. Kinnear[1]

Abstract.— Two hundred samples of leaves of *Lycium andersonii* A. Gray, each representing one plant and divided among six different locations, were assayed by emission spectrography. Information for 12 different elements is reported in terms of concentrations, frequency distribution, correlations, and some soil characteristics. The objective was to ascertain the nature of variability for mineral elements within a species. Composition varied significantly for all 12 elements among locations, all within about 20 km. At least part of the variation was due to soil characteristics. Samples from Rock Valley were highest in K, Na, and Li, which effect is associated with volcanic outcrop. Samples from Mercury Valley were highest in P, Mg, Ba, and B. At least Mg is related to the soil composition. Correlation coefficients between element pairs were often very different for all 200 samples versus those obtained for individual locations. Some of the values for all 200 samples together proved to be artifacts. The highest correlation was for Ca × Sr (positive) and next was Ca × Mg (also positive). Most correlations were slightly or strongly positive (24 of 32). Only P × Ca, Ca × Na, Ca × B, and Sr × P seemed to be significantly negative of the 32 correlations examined. Frequency distribution patterns where common populations were grouped were often normally distributed. Li, as previously reported, and Na, Cu, Mn, and B and Ba at some locations were not normally distributed. Wide variations in the concentrations of individual elements in leaves of these species were encountered.

Mineral composition of the plants in any ecosystem is one of its distinguishing characteristics. The essential nature of at least 13 mineral elements for plants, with their abundance in soil, in many cases helps to determine the nature of the vegetational pattern. The same also can be said for some nonessential elements. In fact, excesses of both essential and nonessential elements largely determine vegetational characteristics under many conditions, and this occurrence is very common in desert ecosystems where young, poorly leached soils are usually involved (Fuller 1975, Romney et al. 1973).

The purpose of this report is to explain in some detail the mineral compositon of leaves of one plant species occurring with fair abundance in the northern Mojave Desert. The species, *Lycium andersonii* A. Gray, accumulates relatively high levels of Ca and Li and characteristically avoids salinity (Romney et al. 1973, Wallace et al. 1973, Ashcroft and Wallace 1976). Such data also would help to indicate the presence of ecotypes. Data for Li in these plants were reported previously (Romney et al. 1977).

Materials and Methods

Lycium andersonii samples were collected in May 1976 from six different areas in the southern portion of the Nevada Test Site (northern Mojave Desert). The areas were Mercury Valley, west Mercury Valley, Rock Valley, base of Skull Mountain in Rock Valley (near 410 road), Frenchman Flat, and southwest Frenchman Flat. Each sample consisted of about 2 g of dry leaves that involved about 2000 individual leaves for each sample. There were 33 or 34 samples from each location and 200 total samples for all the locations. Each sample represented a single plant. Samples were collected just after a series of rains and otherwise were not washed (Al and Ti analysis indicated minimum contamination by soil). The samples were dried, weighed, ground in a plastic mill, and otherwise prepared for analysis by emission spectrography.

The soils characteristics from these areas are detailed in the report of Romney et al. (1973).

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[1] Laboratory of Nuclear Medicine and Radiation Biology, University of California, Los Angeles, California 90024.

Results and Discussion

The mineral composition of leaves from all six locations differed for all 12 elements included in this report (Table 1). The samples from Mercury Valley were highest in P, Mg, B, and Ba. Rock Valley, which is partly overlain with volcanic material and igneous outcrops (Beatley 1976) had leaves with the highest Na, K, and Li.

The Rock Valley samples were also lowest in P, Fe, and Mn, and the southwest Frenchman Flat location was lowest in Cu, Sr, Ba, and Li.

The variability in composition from location to location was largely due to variations

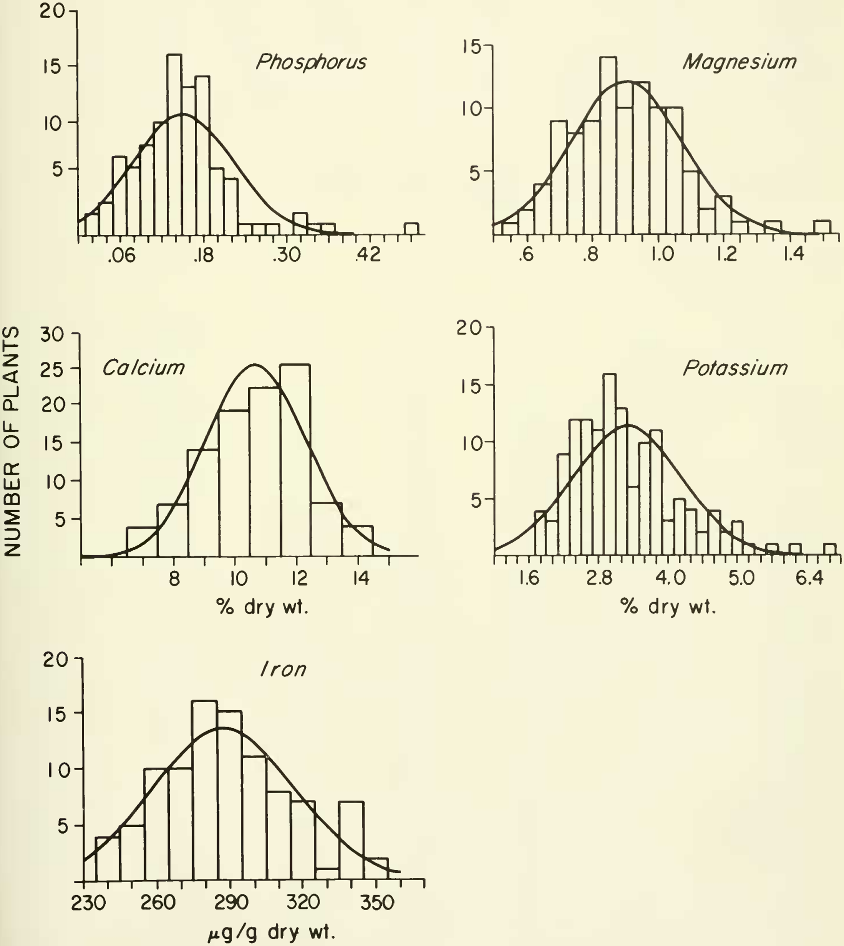

Fig. 1. Frequency distribution of K, Ca, P, Mg, and Fe in indicated groupings of locations for *L. andersonii* leaves in which groupings are not statistically different according to analysis of variance. (K = WM, F, M, 410; Ca = WM, SWF, 410; P = F, SWF, 410; Mg = WM, SWF, 410; Fe = RV, WM, M). See Table 1 for meanings of locations.

TABLE 1. Mineral composition of May 1976 leaves of *Lycium andersonii* from six different locations in the northern Mojave Desert.

	Mercury		Frenchman		SW Frenchman		W. Mercury	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
P, µg/g	2030a	884	1385b	795	1579b	897	1015c	372
Na, %	0.044	0.070	0.024b	0.016	0.025b	0.004	0.148b	0.177
K, %	3.42ab	0.972	3.32b	0.751	2.70c	0.900	2.98bc	0.893
Ca, %	6.72d	1.83	9.47b	1.43	10.74a	1.64	10.51a	1.77
Mg, %	1.78a	0.24	1.06b	0.18	0.94c	0.12	0.88v	0.34
Cu, µg/g	2.58c	1.11	2.97bc	1.28	1.85d	0.84	4.38a	2.34
Fe, µg/g	292cd	23	313b	42	364a	31	287d	38
Mn, µg/g	47b	27	128a	50	87a	27	47b	28
B, µg/g	41.5a	18.5	28.4c	5.8	36.5ab	7.6	35.9ab	10.2
Sr, µg/g	628b	106	550c	101	429d	70	737a	137
Ba, µg/g	56a	17.9	40bc	20.7	34d	4.6	34c	7.0
Li, µg/g	38.5ab	31.0	22.3cd	20.4	14.6d	14.3	44.8abc	36.5
Cation sum me/100 g	574		647		686		682	

[*] Values for each element followed by a common letter are not statistically different at the 0.05 level.

TABLE 2. Correlation coefficients for pairs of elements of *Lycium andersonii* leaves from different locations in the northern Mojave Desert.

Pairs	All locations	Mean for 6 locations	Mercury	Frenchman	SW Frenchman
n	194–200	194–200	33	33	34
P × Ca	–0.28	–0.29	–0.40	–0.12	–0.51
P × Cu	+0.16	0.40	0.11	0.68	0.77
P × B	+0.23	0.21	0.04	0.06	0.38
P × Fe	+0.14	0.00	–0.06	+0.48	–0.03
K × Na	0.30	0.22	0.22	–0.04	0.65
K × Ca	–0.20	–0.07	0.17	–0.27	–0.19
K × Sr	0.25	0.08	–0.13	–0.15	0.09
K × Ba	0.15	0.01	–0.08	0.05	0.10
K × Li	0.29	0.20	0.37	0.29	0.06
Ca × Na	–0.26	0.16	0.05	–0.29	–0.43
Ca × Mg	–0.37	0.46	0.04	0.60	0.57
Ca × Fe	0.34	0.22	0.16	0.22	0.17
Ca × Mn	0.21	0.17	–0.01	0.32	0.21
Ca × B	–0.13	–0.17	–0.19	–0.26	–0.10
Ca × Sr	0.09	+0.50	0.58	0.47	0.60
Ca × Ba	–0.25	0.23	0.46	–0.26	0.01
Ca × Li	–0.08	0.05	–0.11	0.27	–0.11
Na × P	–0.25	0.13	0.01	–0.09	0.64
Na × Sr	0.33	–0.04	0.20	0.04	–0.22
Na × Li	0.32	0.14	0.15	–0.26	0.33
Mg × Sr	0.14	+0.32	0.20	0.48	0.24
Mg × Ba	0.48	0.07	0.04	0.11	0.01
Mg × Li	0.12	0.32	0.18	0.71	0.17
Fe × Mg	–0.09	0.32	0.20	0.48	0.24
Fe × Mn	0.37	0.19	0.07	0.33	0.36
Fe × Sr	–0.20	0.42	0.61	0.39	0.13
Fe × Ba	–0.11	0.31	0.26	0.31	0.13
Fe × Li	–0.15	0.11	0.11	0.33	–0.01
Sr × Ba	0.27	0.21	0.20	–0.12	0.41
Sr × P	–0.26	–0.18	–0.38	0.14	–0.36
Sr × Li	0.19	0.02	–0.19	0.28	–0.06
Ba × Li	0.10	0.11	–0.01	–0.02	0.36

[*] r = 0.14 sig at 0.05 for all locations; 0.33 for individual locations.

Table 1 continued.

Rock Valley		Highway 410		F	Prob F	Mean	S.D.	C.V.	LSD
Mean	S.D.	Mean	S.D.	ratio	extended	of all	of all	of all	0.05
957c	407	1525b	463	11.1	0.0000	1423	761	53.5	327
0.951a	0.525	0.033b	0.039	87.1	0.0000	0.198	0.399	201.5	0.108
3.91a	1.356	3.45ab	1.107	5.6	0.0001	329	1.07	32.5	0.49
7.63c	1.73	10.77a	1.54	36.3	0.0000	9.34	2.29	24.5	0.80
1.13b	0.20	0.90c	0.13	105.8	0.0000	1.19	0.36	30.3	0.09
2.72bc	0.99	3.37b	1.04	13.1	0.0000	2.98	1.56	52.3	0.66
282d	26	305bc	36	27.1	0.0000	307	43	40.2	16.1
41b	16	46b	19	44.8	0.0000	66	43	34.6	14.4
32.5bc	11.3	38.8ab	12.6	5.21	0.0002	35.6	12.3	34.6	5.63
756a	109	655b	160	36.2	0.0000	625	161	25.8	56.7
39bc	7.2	41b	10.6	29.2	0.0000	39	15.1	38.7	5.6
54.5a	45.4	30.9bcd	32.8	4.9	0.0004	36.3	35.3	97.2	16.1
617		703		105.8					

Table 2 continued.

West Mercury	Rock Valley	Hwy 410	Location		No. loc. sig. at 0.05	Sig. of all loc.
32	34	34	+	–		
–0.28	–0.32	–0.08	0	6	2	0.01
0.37	0.37	0.10	6	0	4	0.05
0.10	0.20	0.48	6	0	2	0.01
+0.09	–0.28	–0.18	2	4	1	0.05
0.23	0.30	–0.05	4	2	1	0.01
0.16	0.01	0.03	3	3	0	0.01
0.01	0.17	0.47	4	2	1	0.01
–0.21	0.14	0.05	4	2	0	0.05
–0.04	0.54	–0.01	4	2	2	0.01
–0.15	0.03	–0.16	2	4	1	0.01
0.56	0.55	0.44	6	0	5	0.01
0.05	0.33	0.39	6	0	2	0.01
0.21	0.16	0.13	5	1	0	0.01
0.19	–0.63	0.04	2	4	1	0.10
0.38	0.55	0.44	6	0	6	NS
0.22	0.60	0.37	5	1	3	0.01
–0.24	0.27	0.21	3	3	0	NS
0.00	0.04	0.20	4	1	1	0.01
–0.16	–0.05	–0.07	2	4	0	0.01
0.57	0.15	–0.10	4	2	2	0.01
0.11	0.58	0.33	6	0	3	0.05
–0.11	0.36	0.01	5	1	1	0.01
0.16	0.31	0.41	6	0	2	NS
0.11	0.58	0.33	6	0	3	NS
0.12	0.13	0.12	6	0	2	0.01
0.50	0.54	0.32	6	0	4	0.01
0.23	0.52	0.41	6	0	2	NS
–0.08	–0.02	0.31	3	3	1	0.01
0.40	0.57	0.18	5	1	3	0.01
–0.08	–0.41	0.03	2	4	3	0.01
–0.19	0.27	–0.21	2	4	0	0.01
0.03	0.16	0.16	4	2	1	NS

in the edaphic characteristics (Romney et al. 1973). The area with high Mg in leaves (and low Ca) had high available Mg in soil (Romney et al. 1973).

The relationship between Ca and Mg was not always simple. For each of the locations except one, the correlation coefficient obtained when Ca and Mg were correlated was strongly positive (Table 2). The one not significant was at the location having highest Mg and the lowest Ca (r = +0.04), so even then the relationship was not inverse. When all 200 samples were included in a common correlation, however, the r was –0.37 compared with a mean of +0.46 for the six locations determined individually. The overall r then must be considered as an artifact and indicates possible erroneous conclusions that can be made when correlation coefficients are obtained for large variable populations.

Most of the 32 correlation coefficients in Table 2 were positive (24 of them as the average of the 6 locations). This generally conforms to the report of Garten (1976) for data elsewhere. Consistent and important negative correlations were obtained for P × Ca, Ca × Na, Ca × B, and Sr × P. There are known physiological bases for some of these. In addition to Ca × Mg, other strong positive correlations existed between P and Cu (r = +0.40), Ca × Sr (r = +0.50), Mg × Sr (r = +0.32), and Fe × Sr (r = +0.42).

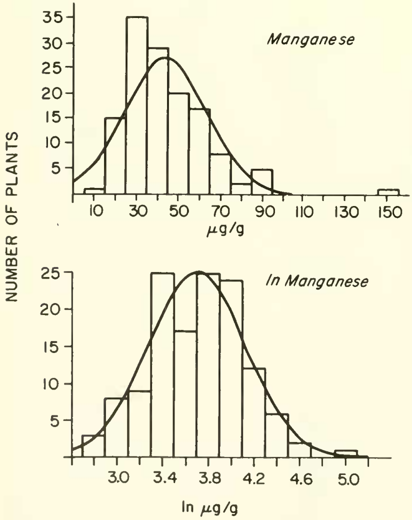

Fig. 2. Frequency distribution of Mn in *L. andersonii* leaves (RV, 410, M, and WM for arithmetic and the same grouping for ln of Mn concentration). See Figure 1 for further explanation.

Frequency distribution patterns of the elements were obtained for groups of locations where analysis of variance data indicated that no differences existed between or among the particular locations. This permitted the use of as many as all samples (200) and, at least, about one-half of them in a frequency distribution determination. Where normal distribution was not apparent, data were also plotted as logarithm-normal. The histograms (Fig. 1) for Ca, Mg, P, K, and Fe with n of around 90 showed normal distribution (Table 3). Manganese did not show a normal distribution (Fig. 2), but it did on the ln normal basis (Fig. 2 and Table 3). Two of three B groupings gave a normal distribution (Fig. 3 and Table 3); a third grouping gave a ln normal distribution (Fig. 3, Table 3).

The Cu concentrations of these *L. andersonii* plants were low in comparison to most plant species. The values were lower than those found for *L. andersonii* collected over a wider area (Wallace and Romney 1972). The Cu values were not normally distributed (Fig. 4) but skewed toward the smaller values (Table 3). When all six sites were combined, a ln normal distribution was obtained even though there were four distinct populations (Table 1). Part of this Cu variation in distribution could be analytical.

Two Ba groupings gave a normal distribution and one did not (Fig. 5, Table 3). Again the ln normal gave a distribution which could not be rejected as normal (Fig. 5, Table 3). Two Sr groupings gave normal distribution (Fig. 6, Table 3).

In the former study of Li where distribution was neither normal nor ln normal (Romney et al. 1977), differential distribution of Li in soil was given as an explanation. In one of the present data groupings, however, Li did give a ln normal distribution (Fig. 7, Table 3). It would appear that this species tends toward a normal distribution of metals, but that soil variation shifts to other types of distribution.

TABLE 3. Evaluation(1) of normality of frequency distribution histograms (Figs. 1–7)

Element	Mean percent	Locations	n	Chi^2 goodness of fit Test of normality	Skewness	Kurtosis(2)
P	0.150	FR,SWF,410	98	Cannot reject	1.2407°°	0.7023°°
Na	0.0550	All except RV	168	Reject	4.2458°°	Not tested
K	3.291	WM,F,M,410	134	Cannot reject	0.9592	0.8031
Ca	10.673	WM,SWF,410	102	Cannot reject	–0.2688	0.8214
Mg	0.903	WM,SWF,410	102	Cannot reject	0.5005°°	0.7933
	ug/g					
Cu_1	2.8	M,RV,FM	98	Reject	0.7430°°	0.7932
Cu_2	3.0	410,RV,FM	99	Reject	0.5837°°	0.8135
Cu_3	2.9	410,RV,FM,M	132	Reject	0.5866°°	0.8178
Cu_4	3.0	ALL	199	Reject	1.4078°°	0.7494°°
Fe	287	RV,WM,M	99	Cannot reject	–0.1201	0.7719
Mn	44.2	RV,WM,M,410	133	Reject	1.5509°°	0.7475°°
B_1	36.0	RV,WM,410,SWF	134	Cannot reject	1.6832°°	0.7069°°
B_2	37.5	WM,M,410,SWF	134	Reject	1.8032°°	0.7008°°
B_3	36.5	WM,RV,M,410,SWF	166	Cannot reject	1.5353°°	0.8875°°
Sr_1	637	M,410	67	Cannot reject	0.9195°°	0.7754
Sr_2	746	WM,RV	66	Cannot reject	–0.2714	0.8198
Ba_1	364	WM,RV,F	99	Reject	0.2980	0.8069
Ba_2	38.8	RV,F,410	99	Cannot reject	0.5407°°	0.7726
Ba_3	37.7	WM,RV,F,410	133	Cannot reject	0.5526	0.7837
Li_1	23.9	F,410,SWF	71	Reject	2.3171°°	0.7028°°
Li_2	31.6	F,410,M	78	Reject	1.5474°°	0.7631
Li_3	37.9	WM,M,410	90	Reject	1.1725°°	0.7918
Li_4	46.4	RV,WM,M	88	Reject	0.9633°°	0.8054
ln Li_4	3.391	RV,WM,M	88	Cannot reject	–0.6095°°	0.8127

(1) Statistical significance level for all tests is 5 percent.

°°Indicates significance

(2) Alternate kurtosis index proposed for N < 200 by R. C. Geary. See Snedecor & Cochran *Statistical Methods*, 6th ed., 88; and R. C. Geary, *Biometrika* 28, 295 (1936) (Index is about 0.80, depending on sample size. Table of probability points is in reference).

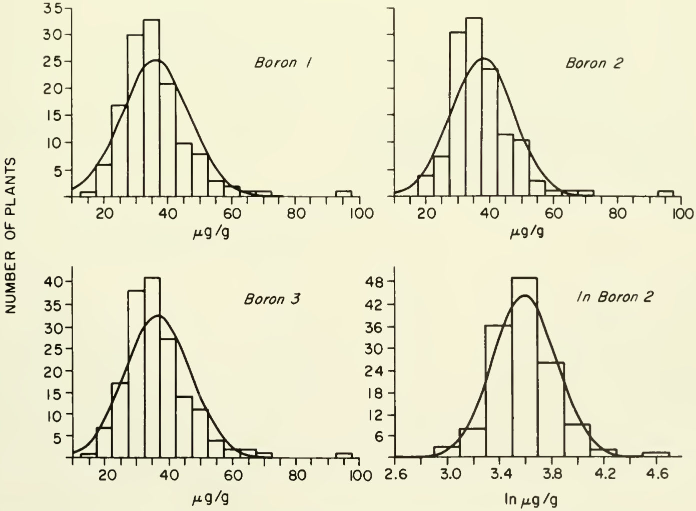

Fig. 3. Frequency distribution of B in leaves of *L. andersonii* (Boron 1 = RV, WM, SWF, 410; Boron 2 = WM, SWF, 410, M; Boron 3 = RV, WM, SWF, 410, M). See Figure 1 for further explanation.

A cluster tree for 21 elements in all samples of *L. andersonii* leaves is shown in Figure 8. Calcium, the dominant mineral element in *L. andersonii* leaves, clusters with Cr. These in turn cluster closely with the so-called dust elements Fe, Ti, Al, Si, and in this case also Mn. The trace metal Li that is prominent in *L. andersonii* (the species is an accumulator of Li) clusters with another monovalent metal, Na, which also is in *L. andersonii* in trace quantities only. These two elements are joined by the monovalent K, which is present in leaves of this species at levels of from about 2 to 5 percent. These three elements later join with Cu, V, and Sr. Mg and Ba are clustered and these join with

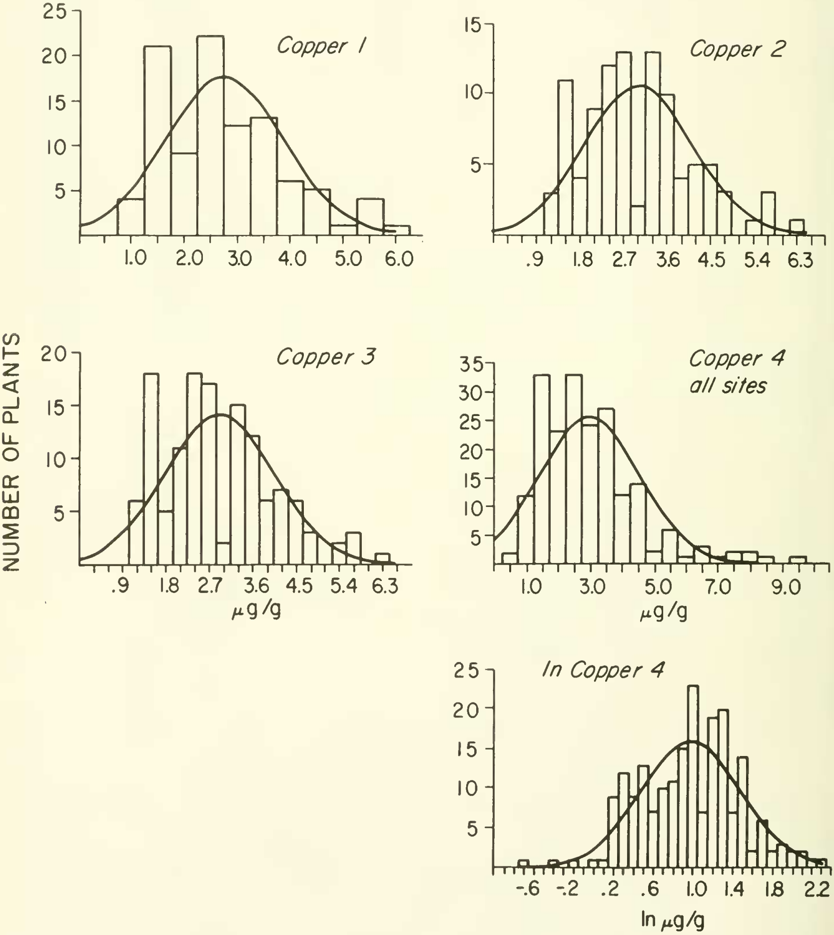

Fig. 4. Frequency distribution of Cu in leaves of *L. andersonii* (Copper 1 = M, RV, F; Copper 2 = RV, F, 410; Copper 3 = M, RV, F, 410; Copper 4 is all six sites combined). See Figure 1 for further explanation.

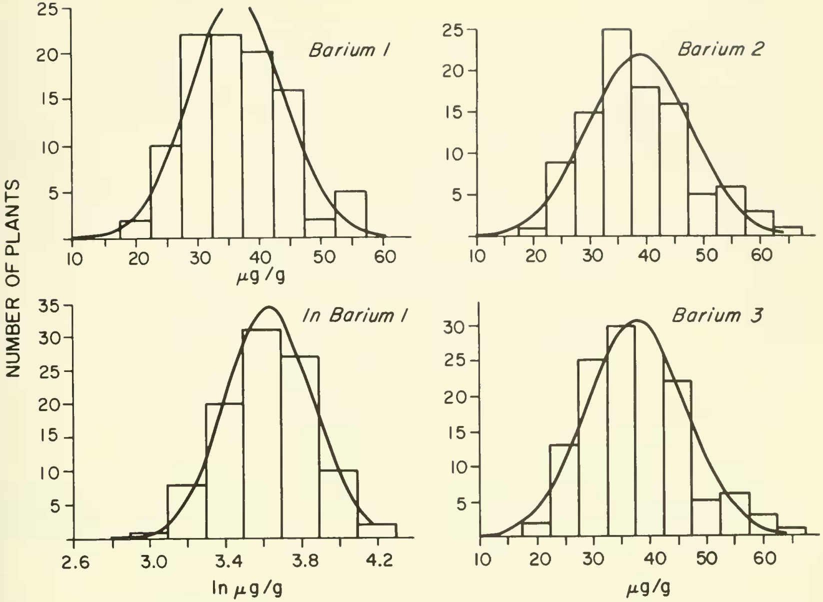

Fig. 5. Frequency distribution of Ba in leaves of *L. andersonii* (Ba 1 = WM, RV, F; Ba 2 = RV, F, 410; Ba 3 = WM, RV, F, 410). See Figure 1 for further explanation.

P. These interactions as yet have not been used to explain behavior of this species in the northern Mojave Desert, but opportunities are present.

Acknowledgments

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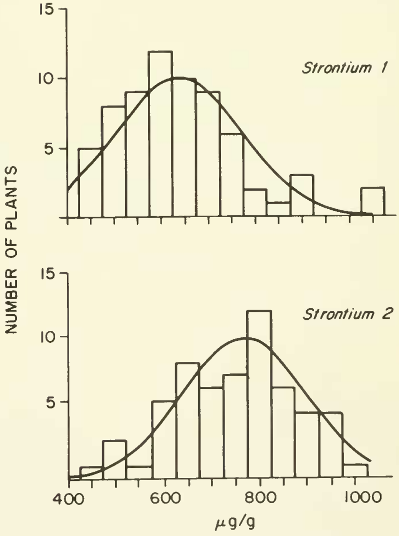

Fig. 6. Frequency distribution of Sr in leaves of *L. andersonii* (Sr_1 = M, 410; Sr_2 = WM, RV). See Figure 1 for further explanation.

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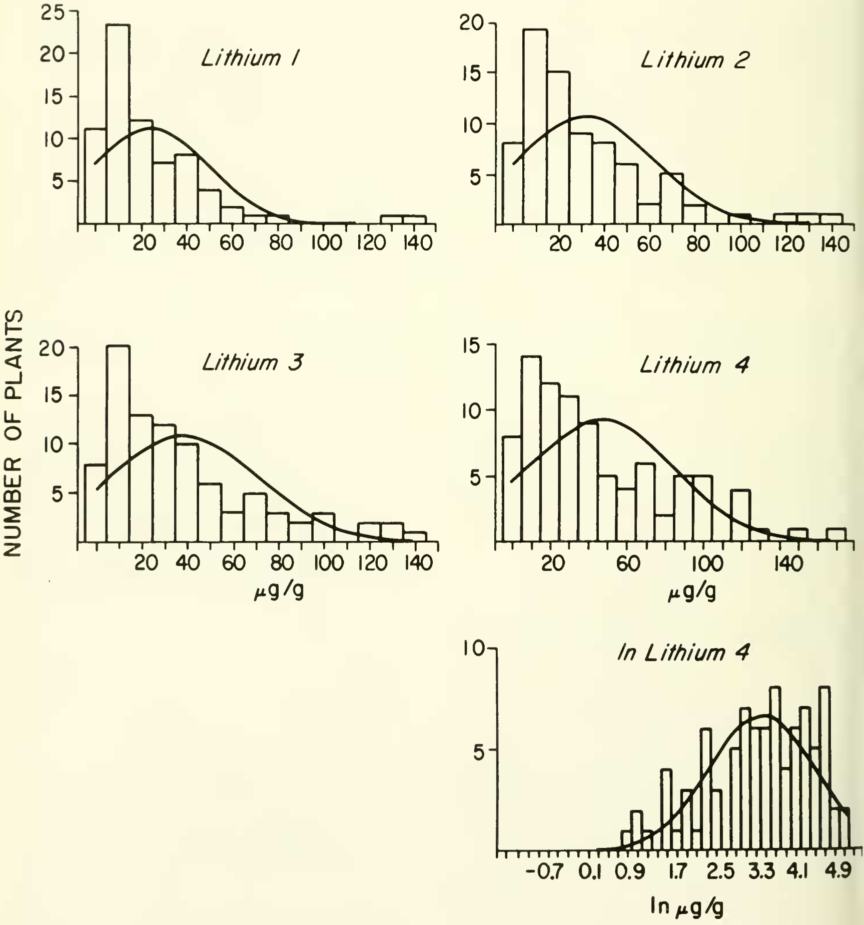

Fig. 7. Frequency distribution of Li in leaves of *L. andersonii* (Li 1 = SWF, F, 410; Li 2 = F, 410, M; Li 3 = 410, M, WM; Li 4 = M, WM, RV). See Figure 1 for further explanation.

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TREE PRINTED OVER CORRELATION MATRIX (SCALED 0-100).
CLUSTERING BY AVERAGE DISTANCE METHOD.
   VARIABLE
NAME    NO.
             -------------------------------------------------------------/
P       (  2) 61 61/40 50 55 56 63 35/61 54 57/49/49/36 48 55 58 58 55 51/
                  /                 /        /  /  /                    /
             ----/                 /        /  /  /                    /
MG      (  6) 77/49 55 56 42 49 57/54 42 51/49/49/34 46 47 41 36 37 46/
               /                 /        /  /  /                    /
              /                 /        /  /  /                    /
BA      ( 19)/51 59 57 58 65 68/52 43 50/49/49/39 44 44 40 40 43 40/
                              /        /  /  /                    /
             ----------------/        /  /  /                    /
NA      (  3) 68/64/50 53 65/45 45 48/49/49/38 38 39 47 38 39 37/
               /  /        /        /  /  /                    /
              /  /        /        /  /  /                    /
LI      ( 20)/63/55 63 62/50 50 48/49/49/45 46 42 46 43 43 36/
               /        /        /  /  /                    /
              /        /        /  /  /                    /
K       (  4)/48 56 61/54 60 53/49/49/42 42 42 45 42 44 44/
                     /        /  /  /                    /
             -------/        /  /  /                    /
CU      (  7) 68/60/48 46 48/49/49/53 57 46 48 50 49 44/
               /  /        /  /  /                    /
              /  /        /  /  /                    /
V       ( 14)/66/46 56 50/49/49/58 60 45 46 52 53 43/
               /        /  /  /                    /
              /        /  /  /                    /
SR      ( 18)/51 58 48/49/49/57 54 43 40 40 43 36/
                     /  /  /                    /
             -------/  /  /                    /
B       ( 10) 63/50/49/49/44 44 53 53 53 54 42/
               /  /  /  /                    /
              /  /  /  /                    /
MO      ( 16)/53/49/49/57 47 53 51 57 60 50/
               /  /  /                    /
              /  /  /                    /
PB      ( 22)/49/49/46 46 46 48 48 48 47/
               /  /                    /
              /  /                    /
SN      ( 21)/49/49 49 49 49 49 49 49/
               /                    /
              /                    /
NI      ( 15)/49 49 49 49 49 49 49/
                                 /
             -------------------/
CA      (  5) 79/66 56 69 66 59/
               /              /
              /              /
CR      ( 17)/67 59 65 62 64/
                           /
             -------------/
FE      (  8) 87/88 86/68/
               /     /  /
              /     /  /
TI      ( 13)/85 83/62/
                  /  /
             ----/  /
AL      ( 11) 97/65/
               /  /
              /  /
SI      ( 12)/64/
               /
              /
MN      (  9)/
```

Fig. 8. Cluster tree derived from correlation matrix of mineral element composition of *L. andersonii* leaves. The values in this tree have been scaled 0 to 100 according to the following: Value above 0, correlation –1.000; value above 5, correlation –0.900; value above 10, correlation –0.800; value above 15, correlation –0.700; value above 20, correlation –0.600; value above 25, correlation –0.500; value above 30, correlation –0.500; value above 35, correlation –0.300; value above 40, correlation –0.200; value above 45, correlation –0.100; value above 50, correlation 0.000; value above 55, correlation 0.100; value above 60, correlation 0.200; value above 65, correlation 0.300; value above 70, correlation 0.400; value above 75, correlation 0.500; value above 80, correlation 0.600; value above 85, correlation 0.700; value above 90, correlation 0.800; value above 95, correlation 0.900.